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A fairytale creation or the beginning of everything: Students' pre-instructional conceptions about the Big Bang theory

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Summary The beginning of the universe, the Big Bang, being an important subdomain in cosmology, marks the very beginning of space and time. Therefore, it has formed the modern scientific worldview. Transferring this to students through science teaching is a frequent request in science literacy discussion (e.g., American Association for the Advancement of Science, 1993; Schecker et al., 2004).

However, it is not yet clear in science education if students' conceptions about the Big Bang vary by nationality, and therefore, if it is possible to apply the same teaching modules to students from different countries, who may have diverse social and cultural backgrounds and different curricula. These conceptions with which students enter the classroom were investigated in our study. We implemented an open-ended questionnaire survey in Germany, with questions based on recent U.S. studies. The results clearly showed, with high interrater reliabilities, widespread misconceptions like the Big Bang being an explosion of preexisting matter into empty space or the universe having a centre. Furthermore, a comparison of results from researchers in the USA, Sweden and Germany allowed us to identify differences in students' conceptions between the countries. Our findings appear to indicate that German students have slightly better pre-instructional conceptions about the Big Bang theory.

Introduction

A commonly used and important research method in the field of science education for building teaching modules in different subjects is the prior investigation of students' conceptions (Ausubel, 1968; Anderson, 2007). These must be

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taken seriously and should be used as the basis for developing teaching modules to help students move toward a better understanding of the current knowledge in science. Since it is often stated that the student's mind is not a blank slate on which new information can just be written (e.g. Bransford et al., 2000), we can help students and support them in effective learning by building upon their existing conceptions. As an example, in the U.S. teaching materials ''designed to help [···] science teachers assess their students' existing conceptions and incorporate knowledge of them into planning lessons'' are regularly published by the National Science Teachers Association (Larkin, 2012, p. 928).

On behalf of the ministers of education and cultural affairs of the German states, Schecker et al. (2004) suggested recommendations for designing physics lessons for upper secondary schools. These suggestions contain the development of a deepened understanding of the modern worldview including astrophysics and cosmology as core content of physics education in upper secondary school. Apparently, there is a need for education development concerning better approaches for teaching certain topics in modern physics such as cosmology (Schecker et al., 2004). Furthermore, the interest of young people in the domain of astrophysics and cosmology is above-average as stated in the Relevance of Science Education (ROSE) study (Schreiner and Sjøberg, 2004). One result is students' strikingly high interest in astrophysics and the universe, irrespective of their country or gender. In addition, teaching about scientific working methods and the concepts of Nature of Science (NOS) can be well illustrated by means of cosmology. For example the interaction between experimental and theoretical physics concerning the pillars of the Big Bang theory can be demonstrated, that is, how theory is adjusted according to observations or how experimental data are proving predictions already made by theory. A second example is the use of combinations of different disciplines of physics to make predictions and receive results. To discover the expansion of the universe, distances have to be measured, spectra have to be analyzed and hence the velocities of the galaxies calculated, by which they are moving away from us due to expanding space. For this optical physics, atomic physics, relativistic elements and astrophysics for stellar evolution (to gain distances e.g., for pulsating stars or supernovae) is needed. Cosmology is one of the very few areas in physics, where you cannot perform any direct experiments. Nevertheless, many discoveries have been made due to the successful interaction of various areas of physics. Furthermore, this area shows the change and provisional nature of scientific worldviews. Our knowledge is not fixed but changes constantly with new discoveries. All these various aspects therefore show the relevance of cosmology in education.

CERN — one of the world's largest international research centres focused on particle physics — also places great importance on education. Given that the Big Bang theory strongly influences the modern scientific worldview, and cosmology represents the connection between particle physics and astrophysics, CERN intends to develop a teaching module for cosmology in different languages. But what are the students' pre-instructional conceptions in that area and is it possible to use the same module in different countries?

The Big Bang has little to do with everyday life, therefore, it can be expected that a wide range of ideas will be formed. Currently, there is a lack of scientific research concerning students' pre-instructional conceptions in cosmology. The results of our study will help to fill this gap and to build a teaching module for cosmology.

Research background

The importance of students' conceptions

A student's conception is an idea of a fact, process or concept she or he has, based on experiences in everyday life, instruction, media and so on. A pre-instructional conception or preconception is ''an idea or opinion formed before enough information is available to form it correctly'' (Cambridge University Press, 2014). The study of students' conceptions and their change is a wide field of research, as demonstrated by a regularly updated bibliography containing thousands of publications (Duit, 2009). This field has developed into a focus in physics education research (Schecker, 1985; Bransford et al., 2000; Larkin, 2012). In the opening pages of his textbook on educational psychology Ausubel (1968) wrote: ''If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly'' (p. vi). Even young children cannot be considered as ''tabula rasa'', therefore, ideas cannot just be imparted; for the development of learning provisions the learner's whole cognitive organization should be known (Jung, 1978). Students entering the classroom normally have already developed deeply embedded conceptions constructed on the basis of everyday experience and informal learning, from sources such as TV, Internet, books or other printed media. Most of these conceptions are not consistent with the scientific view — one origin of many learning difficulties (Duit, 1995; Amin et al., 2014). Duit is stating further that learning chemistry and physics means to actively build knowledge upon the existing conceptions: students can only ''see'' something new through the filter of already known and familiar things. Furthermore, Duit said that there are also conceptions which are invented ''ad hoc'', when students are confronted with something new. Nevertheless, these conceptions also have to be taken seriously.

In the last decades, many studies have been conducted in that field of research in physics, mainly on the conceptions of mechanics, energy, electricity and magnetism, heat and temperature, optics and the nature of matter (e.g., Champagne et al., 1980; Gunstone and Watts, 1985; Erickson, 1979; Kristyanto and Berg, 1991; Stead and Osborne, 1980; van den Berg and Osborne, 1990; Cohen et al., 1983; McDermott and Shaffer, 1992; Ayas et al., 2010; Gómez et al., 2006). Müller et al. (2011) present a summary of German literature of students' conceptions in the different areas of physics mentioned above. Furthermore, there are cross-cultural studies such as Trumper et al. (2000), Eckstein et al. (1993), Lynch (1996), Shipstone et al. (1988) and Liu (2005). In general, students' conceptions mostly seem to be similar across countries. ''The reported cross-cultural results indicate the similarity of *types* of alternative

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conceptions, not so much their relative *frequencies* in a population of students'' (Thijs and Van den Berg, 1995, p. 327). Still it does not seem to be completely clear yet how much influence the cultural background or language really has on the development of concepts and science learning. On the one hand, there are statements like ''... culture and differences in man-made aspects of the environment may have only limited influence on the formation or construction of certain physics conceptions'' (Thijs and Van den Berg, 1995, pp. 325/326), and on the other hand, ''... a student's cultural background is likely to affect their ability to fully comprehend and manipulate scientific concepts'' (Baker and Taylor, 1995, p. 698). Therefore, below the issues ''culture'' and ''language'' as well as cross-cultural studies will be addressed a little deeper.

Looking at the issue ''language'', it seems to be uncontroversial that it ''has a significant effect on concept interpretation and, therefore, on the learning of science'' and ''scientific concepts are best learned and understood in the students' mother tongue'' (Baker and Taylor, 1995, p. 696). Everyday language can complicate the development of scientifically approved concepts. For example, it includes conceptions, which do not correspond to the modern worldview such as ''the sun rises''. Sometimes terms are used in physics, which have a different meaning in everyday language, for example, ''force'' or ''energy'' (Jung, 1986).

Regarding cultural factors such as the environment, traditional values and beliefs or social structures, they seem to be ''very important in the science learning and teaching process'' (Thijs and Van den Berg, 1995, p. 329). There are indications that ''concept development in school science is affected strongly by social influences, especially students' socially determined preconceptions and predilections. This intuitive life-world knowledge is constructed during students' early childhood socialization and enculturation by significant others'' (Baker and Taylor, 1995, p. 697).

Predominantly, cross-cultural studies show the same students' conceptions regardless of their country. Trumper et al. (2000), for example, reported minor differences when comparing the students' conceptions of energy in Israel and Argentina and concluded that the students' conceptions ''appear to be independent of the particular culture in which they live'' (p. 709). Yet, some cross-cultural studies indicate the existence of differences between countries. In a comparison between Scotland and Malaysia in their students' use of science word meanings covering a range of fundamental concepts (e.g., temperature and liquid), differences are revealed, and seemed ''most likely to be brought about by cultural effects rather than by, for example, an ability factor'' (Isa and Maskill, 1982, p. 198). Furthermore, as reported in the cross-cultural study of students' alternative frameworks for the nature of matter of Lynch (1996), ''[t]he evidence from this study and from previous studies in the series would suggest that many alternative frameworks are linguistically and/or culturally determined'' (p. 750). Concerning the development of alternative conceptions of motion in Australia, England and Israel, Eckstein et al. (1993) reported that the same categories of answers could be found in all three countries but the development of concepts of motion showed ''substantial differences between Australia and England on the one hand, and Israel on the other hand'' (p. 38). Maskill et al. (1997) investigated young pupils' ideas about the microscopic nature of matter in the UK, Portugal and Greece. Comparing the data of the three countries, they found that ''there are clear cultural differences in the other dimensions of meaning attached to the words tested'' (p. 641). Looking at a survey dealing with alternative conceptions of the universe of German and Taiwanese students before instruction, Liu (2005) found that there are some differences revealed. First the results indicated that ''the students presented their ideas in a consistent manner, regardless of their cultural backgrounds'' (p. 295). However, as ''for the difference between the sample of two countries, the German students show more intention... to explain astronomical phenomena than their Taiwanese counterparts, and thereby presented more precise models with stronger explanatory power'' (p. 295). As to where the students developed their pre-instructional conceptions from of the earth model, Liu said that ''they seem to have frequently received the relevant information from various sources (TV, books, parents, peers, etc.)'' (p. 322).

Therefore, this informal learning could influence the development of pre-instructional conceptions in topics (e.g., cosmology), which are further away from everyday life and where no other ''learning possibility'' — especially no instruction, for example, by a teacher — is provided. This factor might be different depending on the country and could hence lead to cross-cultural differences. This is in contrast to other fields of physics, where there seems to be no significant indications of differences concerning pre-instructional conceptions and cultural factors only seem to have an impact on the effectiveness of instruction in remedying wrong concepts. Preconceptions which have very early roots in childhood and are ''related to sensory experiences, as most physics preconceptions... might be universal'', but those as in cosmology should develop later and such conceptions ''are more susceptible to linguistic and cultural influences'' (Thijs and Van den Berg, 1995, p. 339). Subsequently, for cross-cultural teaching modules, it is possible ''that teaching materials designed for children whose thoughts and ideas have developed in one culture will be inappropriate for children in another'' (Isa and Maskill, 1982, p. 188).

Knowing the students' conceptions: what to do with it? Jung (1986) spoke about direct and indirect help for the teacher. Indirect help is, for example, the possibility for a teacher, to prepare himself in much more detail for a dialogue with a student, in which he or she can give the student insights into the relations between everyday knowledge and scientific knowledge. This might be necessary to prevent a relapse into alternative pre-instructional conceptions after instruction. Direct help is, according to Jung, to adjust instruction based on the students' conceptions. This is realizable in three different ways. The teacher can choose such conceptions as connections, which barely collide or do not collide at all with the scientific view. As an example for this, Jung suggested starting with solar cells as an inexhaustible voltage source instead of batteries while teaching electricity. Students' widespread conceptions of batteries include the idea of stored electricity in batteries, which is then being consumed. In order to avoid this source of misconception, it is advisable to start differently. Another possibility is to directly confront students with the different incompatible perspectives, for example, with an unexpected result of an experiment. The third approach is the tactic of reinterpretation. The teacher starts with the students' conception and brings about a comprehensive restructuring (conceptual change). Students' conceptions are not changed by a single correct explanation, instead it is a process, which can continue for several years. Another option to incorporate students' conceptions into the classroom is an appropriate selection and implementation of instructional media, specific tasks, or examples (Wodzinski, 1996).

Students' conceptions in cosmology

So far, research in cosmology in the age range from high school to the beginning of university or college has been limited to the U.S. (Prather et al., 2003; Wallace, 2011; Bailey et al., 2012; Trouille et al., 2013) and two studies in Germany (Kahnt and Thesing, 2010) and Sweden (Hansson and Redfors, 2006). At present, no comparable survey of students' conceptual cosmology knowledge exists (Wallace, 2011).

Prather et al.'s (2003) study of misconceptions of cosmology prior to instruction involved 961 students including 607 from middle school, 177 from high school (male-only), and 177 from college. They were asked if they had heard about the Big Bang theory and, if so, to describe it. For the question about what existed or occurred just before the Big Bang, a different group of 133 college students were asked the same question, also prior to instruction. The answers were then analyzed inductively. The results showed that 42% of high school and 51% of college students (numbers rounded to the nearest percent) saw the Big Bang theory as a theory describing the creation of the universe; 24% in both groups saw the Big Bang as a theory describing the creation of planetary systems and furthermore, 29% and 42% respectively, believed that the Big Bang was an explosion of some kind. Furthermore, 69% of the 133 college students believed that some configuration of matter existed before the Big Bang. There were clearly differences in these results because of the age differences in the sample. A difficulty in using the results of the high school and college students for a comparison with those of our study was due to some missing data in a more detailed presentation of the categories found as well as the fact that the high school sample consisted only of males.

More than 2300 students in three different terms of the general education introductory astronomy course (Astro 101) took part in the extensive study of Wallace (2011). Every item under consideration for this study was answered by about 560 students. Scoring rubrics were constructed when they had collected all the responses, so they ''are therefore based on a detailed, iterative, qualitative analysis of actual student responses'' (Wallace, 2011, p. 68). The results revealed common misconceptions like the Big Bang being an explosion of preexisting matter into empty space or that all matter flies away from a centre into already existing regions of space. Additionally, some students considered the ''expansion of the universe'' as an increase of knowledge caused by new discoveries.

In another U.S. study (Bailey et al., 2012), between 219 and 239 students — respectively of Astro 101 and introductory cosmology courses in college or university — answered some of the questions considered for our study. The answers were then analyzed in an ''iterative, constant comparative process of open coding'' (Bailey et al., 2012, p. 7). Furthermore, similar to the results in Wallace's study, about 50% of the students in Bailey et al.'s study stated that the Big Bang was an explosion of some kind; a minority (5%) also said the Big Bang theory was the dinosaur extinction event. Concerning the evidence for the Big Bang theory, about 15% mentioned the expansion, just 1% the Cosmic Microwave Background, and none the third pillar (abundances of the elements). A significant minority (8%) chose ''authority'', such as a teacher or scientific media, as evidence. When asked how the universe changes over time, if at all, 31% mentioned the expansion of the universe. Furthermore, more students (21%) said the universe has always existed, or its age being infinite, than those (11%) who gave its right age of 13—15 billion years.

The most recent study in the U.S. in this area was by Trouille et al. (2013) questioning students in introductory astronomy courses. A mixed methods approach was used including interviews, exam questions and homework essays. In the data analysis procedure they ''carried out an iterative process of thematic coding to generate a comprehensive list of themes'' (Trouille et al., 2013, p. 5). Trouille et al.'s study also revealed some misconceptions such as the Big Bang being an explosion, the Big Bang theory describing the creation of planets and/or the solar system or the universe having always existed.

There were several difficulties concerning a comparison between the results of Trouille et al.'s study and those of our study reported in this article. First of all, different methods were used and the questions for the pre-course homework essays were not separated into different items, so that the students did not have to address all of them. Therefore, only those answers that were addressing that special topic were taken into account for the statistics. Second, some results were obtained after instruction; and for the homework essays, different sources could have been used, and therefore, the results did not necessarily represent the students' conceptions. Third, the sample size was not very large, so it is questionable how representative the results really were.

In the German study by Kahnt and Thesing (2010) 710 students from 7th to 12th grades (of about 12—18 years old) took part. A system of categories was built and 80% of all answers could be categorized with Cohen's Kappa value of 0.77 for interrater agreement (see Bortz and Döring, 2006). About 32% of all the answers to the questions associated with the Big Bang, included the idea of an explosion. While estimating the age of the universe, about 31—41% of the students (depending on their age) stated that the universe has always existed. Unfortunately, there were very few details specified and many results of the answers to the questions were not shown. Additionally, the variance in students' age was quite large, and therefore, their conceptions might change while becoming older as the results concerning the age of the universe already indicated.

The Swedish study of Hansson and Redfors (2006) included 88 students of the last year of upper-secondary school (of normally 18—19 years old). Categories were then constructed inductively. Sixty-three percent of the students mentioned the expansion or growing of the universe as a change and 32% stated that the universe has always existed.

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Unfortunately, the questions asked differed slightly from those in the U.S. studies and it is not clear, if some students already have received instruction in cosmological topics before. Furthermore, it was a specific sample since all of the students were attending the natural science program within which all of them chose the most advanced regular physics course.

So there are clearly difficulties when comparing the different results due to the samples with varying age and instructional background, and differing questions and categories, as well as varying methods. Nevertheless, there is a slight indication that differences in students' cosmological conceptions between countries exist, suggesting the need for a continual, systematic investigation. This can provide information about the range of ideas and answer the question of whether there is a need to vary teaching modules for different countries. If the frequencies of the categories in the answers differed significantly, different sequences in a teaching unit as well as different focuses can, for example, be applied, because there is normally only limited time for every topic in school or university. In that manner, it could also be important to know, if some categories only appear in certain countries, in order to create carefully designed instructional sequences.

Research questions and design

The current state of research appears as rather inconclusive, which can result from the following: the use of different questionnaires, differing samples, and differences in informal learning. The third aspect was not investigated, but only the first two aspects were considered, in this study. In order to investigate the assumption, that students' conceptions in cosmology might differ between countries, another representative country had to be chosen, for comparison with the U.S. studies, which were by far the most detailed ones (see last section of this article). For no particular reason, as it could have been any other country, Germany was chosen for the comparison in our study. Only one country was picked because otherwise either the same sample size was needed or variance would have been brought in causing additional effects, which are not easy controllable. Therefore, the following research questions for our study can be derived:

(1) What are the German students' conceptions about the Big Bang theory?
(2) Can the results of the German study of Kahnt and Thesing (2010) be replicated?
(3) To what extent do the German students' conceptions differ from those in other countries?

Sample

We collected and analyzed the data taken from 11th- and 12th-grade classes (16—20 years old) in German schools before any instruction took place, if at all, because the teaching module is intended for students of that age group. Furthermore, this sample of students allows a comparison with other studies because their age differs not too much from students starting college or university. One hundred twenty-six students aged 16—20 from six classes in schools in three different federal states in Germany took part in the study. Among the schools were five Gymnasiums and a comprehensive school (Gesamtschule). More information about the German school system and school types can be found in TIMSS Encyclopedia (2007).

Questionnaire development

To approach the first research question, eight different open-ended questions were selected, which focused on the Big Bang and the evolution of the universe, since this is one of the major themes in cosmology. For comparability and to answer the third research question, the questions were taken from a larger sample of questions out of four U.S. studies (Prather et al., 2003; Wallace, 2011; Bailey et al., 2012; Trouille et al., 2013). They were translated into German and then cross-checked by two experts. Shown below is the complete adapted questionnaire for our study in its original form in English:

1. Think about the Big Bang theory and answer the following (Bailey et al., 2012):
   (a) Explain the Big Bang theory in your own words.
   (b) Describe what evidence you think supports the Big Bang theory.
2. Describe what existed or occurred just before the Big Bang (Prather et al., 2003).
3. Describe how you think the universe changes over time, if at all (Bailey et al., 2012).
4. Explain, in as much detail as possible, what astronomers mean when they say ''the universe is expanding'' (Wallace, 2011).
5. What is the age of the universe? (Trouille et al., 2013)
6. If you could travel to any location in the universe, could you ever see the centre of the universe? Explain your reasoning (Wallace, 2011).
7. If you could travel to any location in the universe, could you go to a place where there would be no galaxies in front of you? Explain your reasoning (Wallace, 2011).

The students were asked to complete the questionnaire using their knowledge and/or their ideas in normal class situations under the supervision of their teacher. They should also briefly indicate when they could not provide any answer at all. Completing a questionnaire took between 5 and 30 min with an average of about 14 min (the time was clocked in one of the six classes).

Questionnaire — parameters

Qualitative analysis techniques (Mayring, 2010) were used for the analysis and interpretation of the students' responses. A disjoint set of categories was developed on the basis of the students' answers, meaning that the categories are independent of each other so that a statement fitting into one category do not fit automatically into another. However, answers can fit into different categories simultaneously, because open answers (answers to open-ended questions) usually include more than one statement. A

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Table 1 Number of categories, statements and mean statements per student for each question.

Question	Number of categories	Number of statements	Mean number of statements per student
1a	22	388	3.1
1b	13	150	1.2
2	13	231	1.8
3	13	280	2.2
4	11	191	1.4
5	10	160	1.3
6	16	342	2.7
7	12	266	2.1

Table 2 Cohen's Kappa for the different categories of the open-ended questionnaire.

Open-ended questions	Categories	Cohen's Kappa
(1a)	Formation/development of the universe	1
	Explosion of some kind	1
	Formation of celestial bodies, solar systems, galaxies	1
	Collision of particles or bigger objects	0.87—1[a]
	Expansion of the universe	1
	Formation of particles, atoms, elements	1
	Others (e.g., supernovae)	0.79
	Explicitly talking about a ''bang''	0.97
	Existence/release of energy	1
	No answer/idea	1
	Beginning/formation of space and time	1
	Talking about religious aspects/god	1
(1b)	No answer/idea	1
	Expansion/Redshift	1
	Others including non-scientific answers	0.95
	Simulation of the Big Bang in accelerators/experiments	1
	Existence or knowledge about celestial bodies	1
	Cosmic Microwave Background	1
	Logic (e.g., ''We exist'')	1
	Formation/existence of life, evolution	1
	Observations on earth (e.g., volcanos, fossils)	1
	There is no evidence	1
	Authority (e.g., teacher or scientific media)	1

[a] Combination of two categories, therefore two values of Cohen's Kappa.

statement can be a part of a sentence or a whole sentence, depending on its meaning and the student's linguistic ability. Table 1 shows the number of categories, the number of statements, and the mean number of statements per student for each question.

For example, the answer (translated): ''Something has caused a huge explosion so that galaxies could form.'' contains two statements and is classified into the categories 'Explosion' as well as 'Formation of galaxies'. The percentage of a category corresponds to the proportion of students who mentioned it in their answers. Very often, one answer contained more than one statement and, therefore, could fit into more than one category. Thus, the sum of percentages of all categories of one question usually exceeds 100%. This data analysis procedure in this study was the same as the one used by other researchers, such as Bailey et al. (2012), to allow for comparability.

Comparison of the coding of all open answers with a second coder showed high interrater reliabilities (for more information about the latter see for example Bortz and Döring (2006)). Overall, the range of Cohen's Kappa values was [0.83—1] with three categories having values between [0.74—0.79]. Tables 2 and 3 provide the value of Cohen's Kappa for the categories stated in this article. The categories are presented in the same order as in the following Tables 4—12, which represent the results and are in descending order of percentages except for Table 12 showing the age of the universe. Only the major or most interesting categories are listed here in this article. The answers to Question 2 and 3 could have given better insights with subsequent interviews and therefore are not shown here. For Questions 6 and 7 the most interesting results are shown. For the other questions, all categories with 10% or more are shown plus categories, which revealed some differences in comparison with other studies. For Question 1b, we took 5% and more, because there are not many categories with high percentage values.

Results

Tables 4—8 show the results of the questionnaire survey in our study, including the confidence interval of 95%, which is derived from the results of six participating schools after Bortz and Döring (2006) as follows:

$$z_{2.5\%} \cdot \frac{\sigma}{\sqrt{n}} = 1.96 \cdot \sqrt{\frac{\sum_{i=1}^{n}(x_i - \overline{x})^2}{n^2}}.$$

All percentages are rounded to the nearest percent. Clearly most of the confidence intervals are quite wide. This is due to the small sample size from six participating schools each with a single class which contained between 18 and 27 students. Therefore, the results from class to class can differ greatly. As a consequence, working with 95% confidence intervals, the expected significant differences are very low and all interpretations have to be done carefully.

Table 3 Cohen's Kappa for the different categories of the open-ended questionnaire.

Open-ended questions	Categories	Cohen's Kappa
4	Expansion, size of the universe increases over time	0.94
	No answer/idea	1
	Non-scientific answers	0.90
	New discoveries/new knowledge	0.96
	Dilation of space	0.96
	Expansion of matter	0.86
	Single objects are moving apart from each other	0.88
	Others (e.g., energy, gas)	0.88
	Formation of celestial bodies or galaxies	0.94
5	A few billion years	1
	13—15 billion years	1
	One trillion years and more	1
	Inaccurate time specification	0.92
	Always existed/age infinite	0.94
	One cannot determine/know	1
	No answer/idea	1
6 & 7	The universe has a centre	0.98
	The universe has no centre	0.94
	The universe has an edge	1

Table 4 Associations with the Big Bang theory (answers to question 1a).

Categories	Percentage responses	Confidence interval
Formation/development of the universe	39%	±11%
Explosion of some kind	30%	±8%
Formation of celestial bodies, solar systems, galaxies	28%	±8%
Collision of particles or bigger objects	22%	±7%
Expansion of the universe	19%	±7%
Formation of particles, atoms, elements	18%	±8%
Others (e.g., supernovae)	15%	±8%
Explicitly talking about a ''bang''	14%	±4%
Existence/release of energy	12%	±12%
No answer/idea	10%	±7%
Beginning/formation of space and time	7%	±7%
Talking about religious aspects/god	2%	±2%

Table 5 Evidence for the Big Bang theory (answers to question 1b).

Categories	Percentage responses	Confidence interval
No answer/idea	39%	±9%
Expansion/Redshift	20%	±11%
Others including non-scientific answers	16%	±6%
Simulation of the Big Bang in accelerators/experiments	9%	±3%
Existence or knowledge about celestial bodies	7%	±3%
Cosmic Microwave Background	6%	±5%
Logic (e.g., ''We exist'')	6%	±6%
Formation/existence of life, evolution	5%	±2%
Observations on earth (e.g., volcanos, fossils)	5%	±6%
There is no evidence	1%	±2%
Authority (e.g., teacher or scientific media)	1%	±1%

Concerning the first research question, Tables 4—8 show many conceptions, German students in the sample of our study had about the Big Bang theory. Almost 40% had one of the correct ideas about the Big Bang theory: the formation or development of the universe (see Table 4). However, almost a third referred to the Big Bang as an explosion. It seems that many of these German students had the conception of a collision of already existing particles or bigger objects (22%), which then led to the Big Bang and expansion of matter into empty space. On the other hand, 7% explicitly mentioned the beginning or formation of space and time; this is not a negligible percentage.

Concerning the evidence for the Big Bang theory (see Table 5), every fifth student talked about the expansion or redshift, one of the three pillars. Six percent mentioned the Cosmic Microwave Background but no student seemed to have heard of the third evidence, the abundances of the elements in the universe. It is very striking that almost 40% could not provide an answer at all. The category ''Simulation of the Big Bang in accelerators/experiments'' appearing only in this study might be due to the fact, that the questionnaire was coming from CERN, with which the students might have drawn some connection while answering Question 1b.

When asked the question ''Explain, in as much detail as possible, what astronomers mean when they say 'the universe is expanding'.'' (see Table 6), 43% stated that the size of the universe increases over time and even 12% talked about dilation of space, which is already a rather abstract concept. But nevertheless, 13% believed that 'expansion' is connected to new discoveries and knowledge in science — an obvious misconception.

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Table 6 Meaning of ''the universe is expanding'' (answers to question 4).

Categories	Percentage responses	Confidence interval
Expansion, size of the universe increases over time	43%	±16%
No answer/idea	19%	±7%
Non-scientific answers	14%	±6%
New discoveries/new knowledge	13%	±7%
Dilation of space	12%	±7%
Expansion of matter	12%	±7%
Single objects are moving apart from each other	11%	±7%
Others (e.g., energy, gas)	10%	±6%
Formation of celestial bodies or galaxies	6%	±4%

Table 7 Age of the universe (answers to question 5).

Categories	Percentage responses	Confidence interval
A few billion years	18%	±6%
13—15 billion years	21%	±14%
One trillion years and more	10%	±5%
Inaccurate time specification	12%	±7%
Always existed/age infinite	6%	±4%
One cannot determine/know	12%	±8%
No answer/idea	10%	±7%

Table 8 Structure of the universe (answers to question 6 and 7).

Categories	Percentage responses	Confidence interval
The universe has a centre	52%	±7%
The universe has no centre	17%	±6%
The universe has an edge	14%	±5%

Concerning the age of the universe (see Table 7), 21% stated an acceptable age (13—15 billion years). Only a small percentage of German students (6%) believed the age being infinite, but at the same time, 12% mentioned that one cannot know or determine the age of the universe. Furthermore, when asked if one could go to a place where there would be no galaxies in front when being able to travel to any location in the universe, around 14% of the German students had the idea of the universe having an edge (see Table 8). It was also revealed that about 52% of the German students believed the universe has a centre, only 17% stated there is no centre.

Tables 9—12 show this study's results in comparison with those of other previous studies in Germany and the U.S. A comparison is not always possible, because the other studies did not necessarily have used exactly the same categories or questions; or these were not fully mentioned, if at all. In that case, no percentage is provided in our comparison and a dash indicates that there is no possible comparison. In none of the studies, errors are given, only percentage values are provided. They are also rounded to the nearest percent.

To answer the second research question is slightly more difficult. The results of Kahnt and Thesing (2010) can only partly be replicated in our study. The proportion of German students' thinking of the Big Bang as an explosion is very similar with about 30% (see Table 9). The percentage of the association of 'formation/development of the universe' with the Big Bang is also comparable, although there is a slightly greater difference. For the results concerning the students' mention of the expansion of the universe (see Table 9) or the age of the universe being infinite (see Table 12) the difference is much more. Furthermore, the category 'formation of the earth' did not appear at all in this study but there was a large percentage in Kahnt and Thesings's study with about 27%. Unfortunately, not many results can be compared because there are not enough reported details concerning the questions, categories, differences in age or definitions of categories, nor are the reported results complete.

While some results are similar, there is an indication of the differences in students' conceptions across the countries (third research question). Concerning the category 'formation or development of the universe' in Table 9, the percentages vary only slightly, being a little higher in Prather et al.'s (2003) and Wallace's (2011) studies. In Prather et al.'s study, only the data from high school and college is considered here for comparison to ensure comparability concerning the age of the samples. The misconception of the Big Bang being an explosion of some kind is widespread, although the percentages are higher among American students. The lower percentages given in Prather et al.'s as well as in Trouille et al.'s studies compared to Wallace's and Bailey et al.'s studies might be due to the following reasons. The participants in Prather et al.'s study were mixed college students while half were entirely high school males, and some other studies indicated a gender gap in students' conceptions in mathematics and science (e.g., Willoughby and Metz, 2009). The data of Trouille et al.'s (2013) study were from homework essays written by the students not being under supervision of a teacher; and therefore, there was the possibility of students using different sources, which did not necessarily represent their own opinions. The much higher percentage values in Wallace's and Bailey et al.'s studies (53% and 50%, respectively) about the Big Bang as 'an explosion of some kind' compared to the students in two German studies (about 30%) (see Table 9) are not inside the calculated confidence interval [22%; 38%] for that category (see Table 4). Therefore, it is very likely that this difference is not coincidental.

While about twice as many German students as American students mentioned a collision of particles or bigger objects, a higher proportion of German students explicitly

Table 9 Associations with the Big Bang theory (answers to question 1a).

Categories	Kahnt and Thesing (2010) DE	Prather et al. (2003) US	Wallace (2011) US	Bailey et al. (2012) US	Trouille et al. (2013) US	This study (2015) DE
Formation/development of the universe	∼[a]25–34% [b]	42–51% [c]	44%	33%	77%[d]	39%
Explosion of some kind	∼[1]32%	29–42%[c]	53%	50%	35%[d]	30%
Formation of celestial bodies, solar systems, galaxies	∼[1]17–44%[b]	24%	–	26%	8%[d]	28%
Collision of particles or bigger objects	–	–	–	9–11%[b]	4%[d]	22%
Expansion of the universe	∼[a]6%	–	12%	9%	15%[d]	19%
Formation of particles, atoms, elements	–	–	7%	6%	–	18%
Others (e.g., supernovae)	–	20–21% [c]	6%	7%	–	15%
Explicitly talking about a ''bang''	–	–	–	–	–	14%
Existence/release of energy	–	–	–	–	–	12%
No answer/idea	–	6–14%[c]	3–6%[b]	13%	–	10%
Beginning/formation of space and time	–	–	2%	1%	–	7%
Talking about religious aspects/god	∼[a]4%	–	–	–	54%[d]	2%

Note. DE = Germany; US = U.S.
[a] Approximation is due to illegibility of histograms.
[b] Percent range due to the combination of different categories, where it is not clear if there is an overlap.
[c] Percent range due to participants differing in age.
[d] Comparison is limited due to the applied method (homework essays).

mentioned the correct association of the beginning or formation of space and time when talking about the Big Bang, although the percentage of the category 'Beginning or formation of space and time' varies greatly among the different classes in this study. Furthermore, this study shows the highest percentage of students talking about the expansion of the universe (19%) in comparison with the other studies. The percentage values of the other studies (except Trouille et al.'s study) are lying outside or just on the edge of the confidence interval of [12%; 26%]. Noticeable is also that about three times as many German students in this study (18%) who mentioned the formation of particles, atoms and/or elements as the U.S. students in Wallace's (7%) and Bailey et al.'s (6%) studies with those values being again outside of the confidence interval of [10%; 26%] (see Tables 4 and 9). The category 'talking about religious aspects/god' was only mentioned in Trouille et al.'s study. It is stunning to find that 54% of students in Trouille et al.'s study mentioned it in their homework essays but only 2% of German students in this study did.

Concerning the evidence for the Big Bang theory (see Table 10), German students seem to have slightly better conceptions based on the mean in the categories 'Expansion/Redshift' and 'Cosmic Microwave Background' — two of the three pillars of the Big Bang theory. 'Authority' is a category being mentioned just by one student in this study because scientific media is part of it. Nevertheless, an authority such as a teacher is only brought up in Bailey et al.'s study as well as 6% believing that no evidence exists in contrast to only one German student stating that. The percentages for these two categories in Bailey et al.'s study are also outside of the corresponding calculated confidence intervals (see Table 5). However, it is striking to find that the third evidence of the Big Bang theory (abundances of the elements in the universe) is mentioned in none of the studies and about one third of the students in two studies cannot provide an answer at all.

Similar differences can be found looking at the meaning of an expanding universe (see Table 11). The percentage of German students, who mention the scientifically correct categories 'Expansion, size of universe increases over time' and 'Dilation of space', is slightly higher compared to U.S. students, whereas the percentage of German students in the scientifically incorrect categories 'New discoveries/new knowledge' and 'Formation of celestial bodies or galaxies' is lower. The idea of 'the expanding universe meaning new discoveries or knowledge', seems to be a common misconception in both countries with remarkable proportions of 19% (U.S.) and 13% (Germany). In addition, 19% of the German students in this study stated to have no idea or did not give an answer at all — many more than those in Wallace's study (see Table 11).

Concerning the age of the universe (see Table 12), about twice as many German students in this study who stated an acceptable age (13–15 billion years) as the American students studied by Bailey et al. who did this, although all the values of this category are still inside the confidence interval of [7%; 35%]. Additionally, a remarkable small

Table 10 Evidence for the Big Bang theory (answers to question 1b).

Categories	Bailey et al. (2012) US	This study (2015) DE
No answer	33%	39%
Expansion/Redshift	15–16%[a]	20%
Others including non-scientific answers	31–33%[a]	16%
Simulation of the Big Bang in accelerators/experiments	–	9%
Existence or knowledge about celestial bodies	12%	7%
Cosmic Microwave Background	1%	6%
Logic (e.g., ''We exist'')	4%	6%
Formation/existence of life, evolution	6%	5%
Observations on earth (e.g., volcanos, fossils)	≥5%[b]	5%
There is no evidence	6%	1%
Authority (e.g., teacher or scientific media)	8%	1%

Note. US = U.S.; DE = Germany
[a] Percent range due to the combination of different categories, where it is not clear if there is an overlap.
[b] Category in Bailey et al. (2012) included only fossils.

Table 11 Meaning of ''the universe is expanding'' (answers to question 4).

Categories	Wallace (2011) US	This study (2015) DE
Expansion, size of universe increases over time	28–38%[a]	43%
No answer/idea	3–5%[a]	19%
Non-scientific answers	1%	14%
New discoveries/new knowledge	19%	13%
Dilation of space	3%	12%
Expansion of matter	–	12%
Single objects are moving apart from each other	–	11%
Others (e.g., energy, gas)	7%	10%
Formation of celestial bodies or galaxies	14%	6%

Note. US = U.S.; DE = Germany
[a] Percentage range from the combination of different categories, where it is not clear if there is an overlap.

proportion of German students in this study (6%), compared to those in the U.S. studies, believed the age being infinite. It is remarkable that 33% of the U.S. students in Trouille et al.'s study mentioned an infinite age in their homework essays, although they could have used several sources. It is also very striking to find that all four percentages for this category in the other studies are clearly outside of the confidence interval [2%; 10%] (see Table 7); and therefore, the differences here are very likely not coincidental. Nevertheless, 13% of the students in this study still believed that one cannot know or determine the age of the universe — another obvious misconception.

Table 12 Age of the universe (answers to question 5).

Categories	Kahnt and Thesing (2010) DE	Hansson and Redfors (2006) SE	Bailey et al. (2012) US	Trouille et al. (2013) US	This study (2015) DE
A few billion years	–	–	18%	18%[a]	18%
13–15 billion years	–	–	11%	30%[a]	21%
One trillion years and more	–	–	8%	10%[a]	10%
Inaccurate time specification	–	–	11%	–	12%
Always existed/age infinite	~[b]31–41%[c],[d]	32%[e]	21%	33%[a]	6%
One cannot determine/know	–	–	–	3%[a]	12%
No answer/idea	–	–	29%	–	10%

Note. DE = Germany; SE = Sweden; US = U.S.
[a] Comparison is limited due to the applied method (homework essays).
[b] Approximation is due to illegibility of histograms.
[c] Percent range due to participants differing in age.
[d] Comparison is limited due to the lack of knowledge of the exact question.
[e] Percentage refers to the students' ''own view'' and not their stated ''physics view''.

Discussion

This study was first aimed at revealing students' pre-instructional conceptions around the Big Bang theory. The results shown above can answer the first research question. There clearly exist widespread misconceptions including, for example, the association of the Big Bang with an explosion of some kind, that the Big Bang was caused by a collision of particles or bigger objects, or that the 'expansion of the universe' refers to new discoveries and/or knowledge. Furthermore, only about every fifth student stated the correct age of the universe or the expansion as one of the three pieces of evidence for the Big Bang theory, and almost 40% could not provide any evidence at all. That clearly indicates a lack of knowledge concerning the pillars of the Big Bang theory, which is the basis of our modern worldview and could also give insights into Nature of Science (NOS), as already stated in this article. One reason why none of the students mentioned the abundance of elements as an evidence for the Big Bang theory could be that this requires a previous knowledge of nuclear physics and nucleosynthesis, and basics of the chemical composition of the universe. For students in high school or even at the beginning of university, this is often not the case. Nevertheless, one has to take into account the small sample size in this study, which can just give a hint of German students' existing conceptions (see the Results section and Tables 4—8).

The second research question cannot be answered conclusively. The results of Kahnt and Thesing's study could only be partly replicated but some results differed quite much from those in this study, such as the students' mention of 'expansion' when asked about the Big Bang theory or their statement that the universe has always existed. However, a comparison is not that easy. Kahnt and Thesing's sample had a large range in age; and furthermore, there are not enough details about the published questions, categories, and definitions of categories to enable us to make comparisons in more detail.

The third research question deals with the investigation of the differences in students' conceptions across different countries. As has already been said, students' pre-instructional conceptions are mainly coming from informal learning. Therefore, it has to be investigated in different cultures, where there might be different informal learning possibilities. As pointed out above, there is an indication of some differences by nationality, for example, when comparing the percentage of students' mention of the age of the universe being infinite, or the slight differences concerning the evidence for the Big Bang theory. For the latter, it appears that German students have slightly better pre-instructional conceptions.

However, one has to be careful with interpretations since there are some limitations for an objective comparison. First of all, no uniform survey instrument yet exists in this area and the questions and categories or the definitions of the categories are not always identical or not even known at all. Additionally, the percentages vary greatly across the different classes and semesters in university. Furthermore, the composition of the samples in the different studies vary by age and background. Moreover, the difference of the results between the studies could also at least partly be explained by the time differences of the different surveys, which took place from the beginning of the 21st century (Prather et al., 2003) up to 2015 (this study). During that time, the way people acquire information on modern science has greatly changed, mainly because of new ways of communication based on the Internet and also better accessibility to information with smartphones, tablets and so on. In addition to this, cosmology is a relatively ''newborn'' precision science, which has been evolving rapidly in the last decade and will most likely continue to evolve in the coming years as well, and so will the people's knowledge about cosmology. However, there are indications of some existing differences in students' conceptions in cosmology across the countries, which warrant exploration in more detail. Therefore, I want to end this section with the last sentence in the report of Maskill et al.'s (1997) study:

''Research carried out on any restricted cultural group, as most educational research is... needs to be interpreted very cautiously before being generalised across cultural boundaries'' (p. 644).

Conclusions and outlook

The results of this study reported here reveal many different and some widespread pre-instructional conceptions of German students around the Big Bang theory. There is clearly a range of ideas, which students had formed already in their environment probably mostly by informal learning, since normally there was not any instruction for these students so far. This aspect should be investigated further. The Big Bang being an explosion or the age of the universe being infinite are just some of the major misconceptions students have across different countries, for example, the U.S. Also notable is the lack of ideas in some aspects, for example, ideas concerning the evidence for the Big Bang theory. These outcomes should be taken into account when preparing cosmology lessons. Teachers should be aware of that problem to be able to plan lessons accordingly. However, the sample size in this study was small and a larger sample size is needed to confirm our findings.

There is also an indication of some country differences between the U.S. and Germany, which should be analyzed in more detail. This aspect raises the question of the transferability of results in educational research between different countries. If students' conceptions are not directly transferable, how accurately must a sample need to be described in order for the results to be generalisable and transferable? In order to investigate this question, researchers need more details and the exclusion of factors such as the use of different questionnaires or time differences between surveys, as well as a standardized test. Therefore, the next step is the development of a closed test instrument on the basis of the study's results. These closed items do not require a text production but ''only'' the selection or assignment of statements, for example, by marking in multiple-choice items. They are economical concerning implementation and evaluation, and therefore, are especially suitable for larger samples. This test will then be applied in studies in several countries with larger samples to ensure the comparability of the results between countries.

Conflict of interest

None of the authors have any conflict of interest.

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